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(56) Documents Cited

GB 2267323 A WO 92/21896 A1 US 4599916 A

(58) Field of Search

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ONLINE DATABASES:CLAIMS

(54) Continuously-variable-ratio transmission with clutches to recirculate in low regime only

(57) A continuously-variable-ratio transmission ("CVT"), for instance of the toroidal-race rolling-traction type, capable of geared neutral and of operating in at least two regimes and including a ratio-varying component ("variator") 41, a power-recirculating epicyclic E, a final drive shaft 1 connectable with the variator by way of one of two alternative driven shafts A, B and an input epicyclic e the input of which is connectable to a prime mover and the two outputs of which are connected to the two alternative driven shafts respectively. One of the regimes includes a "geared neutral" condition, and the power-recirculating epicyclic is associated with clutches 45 - 49 whereby power is recirculated through it in that regime. In the remaining one or more regimes no power is recirculated within that epicyclic, but drive reaches the CVT output by way of appropriate clutches and whichever of the two driven shafts will rise in speed as that regime proceeds.

In an alternative embodiment separate reversing gearing may be included.

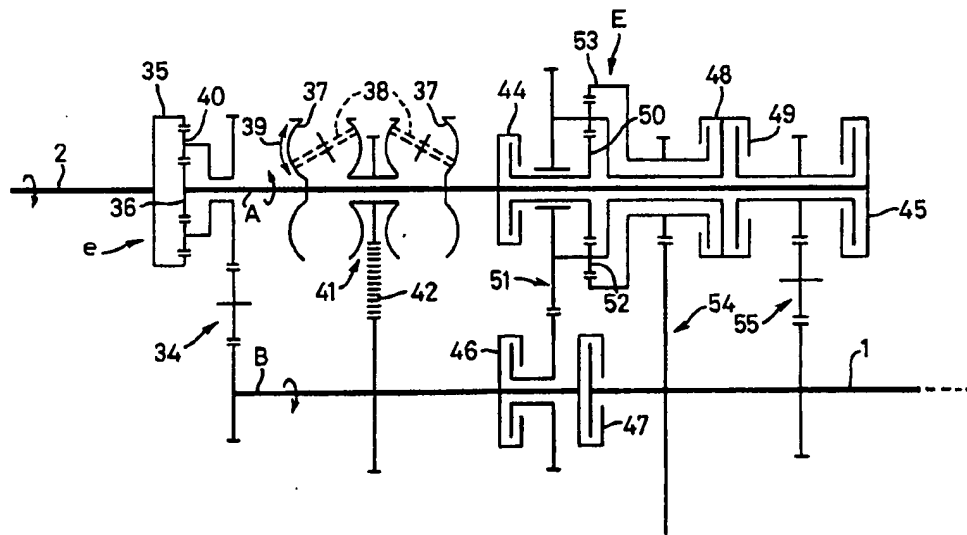


Fig.3

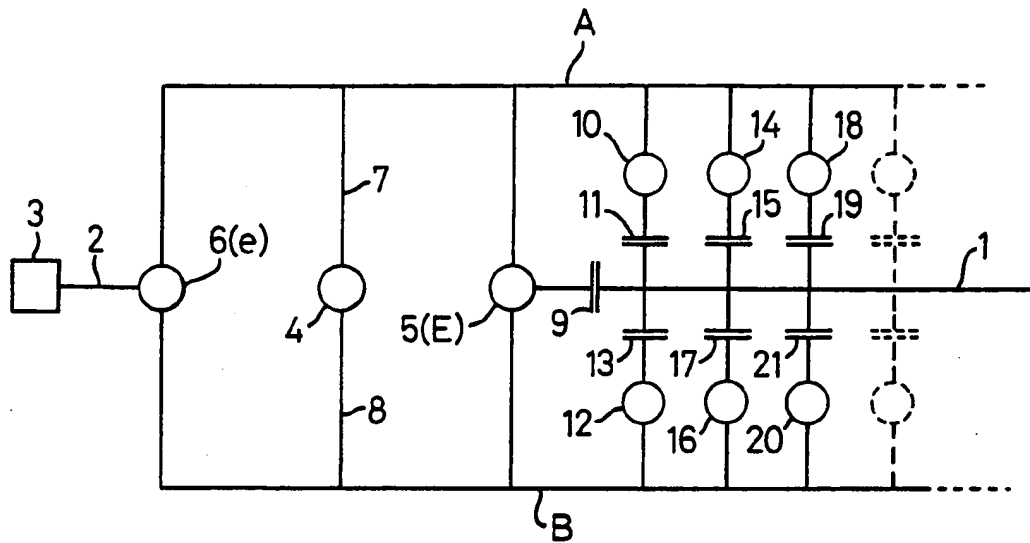


Fig. 1

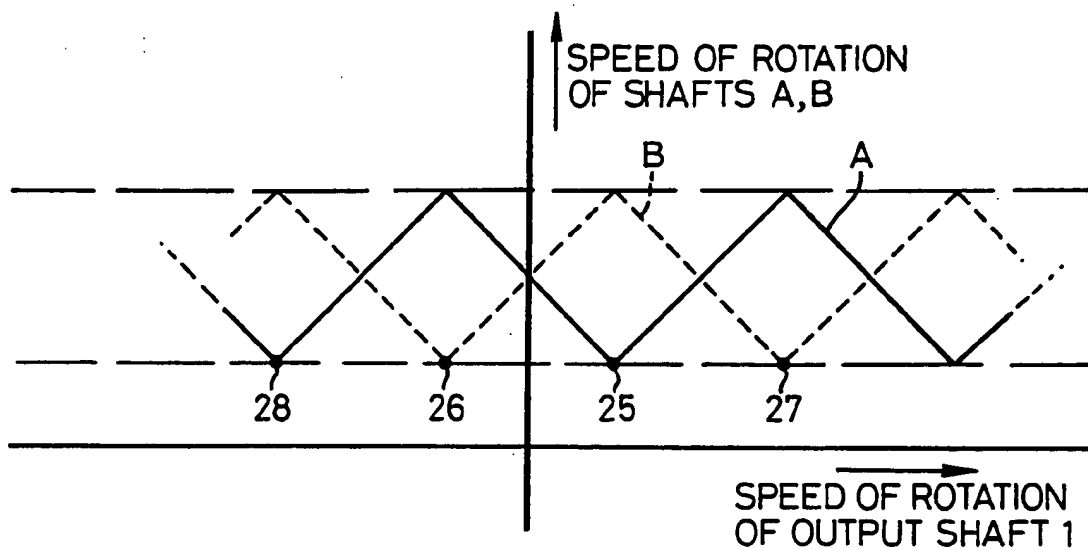


Fig. 2

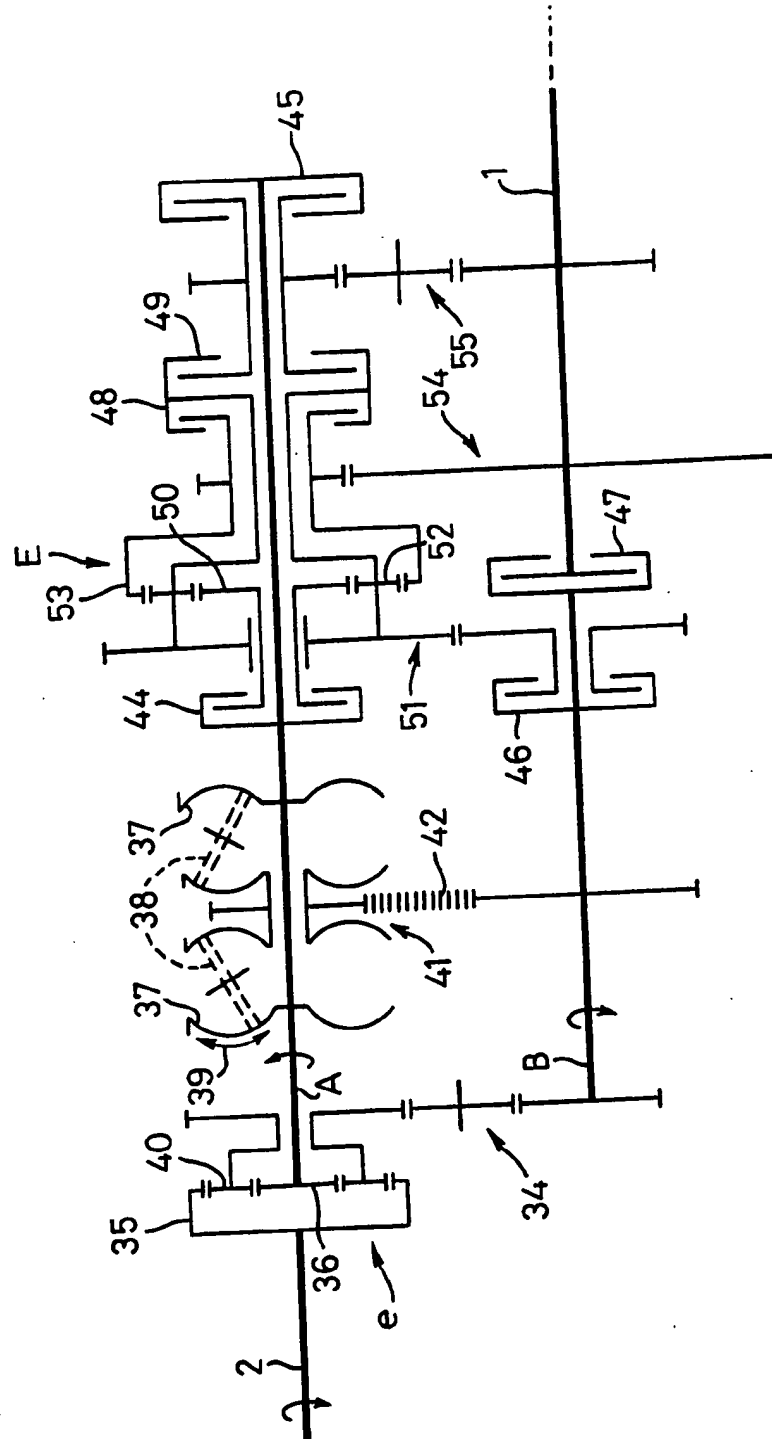


Fig. 3

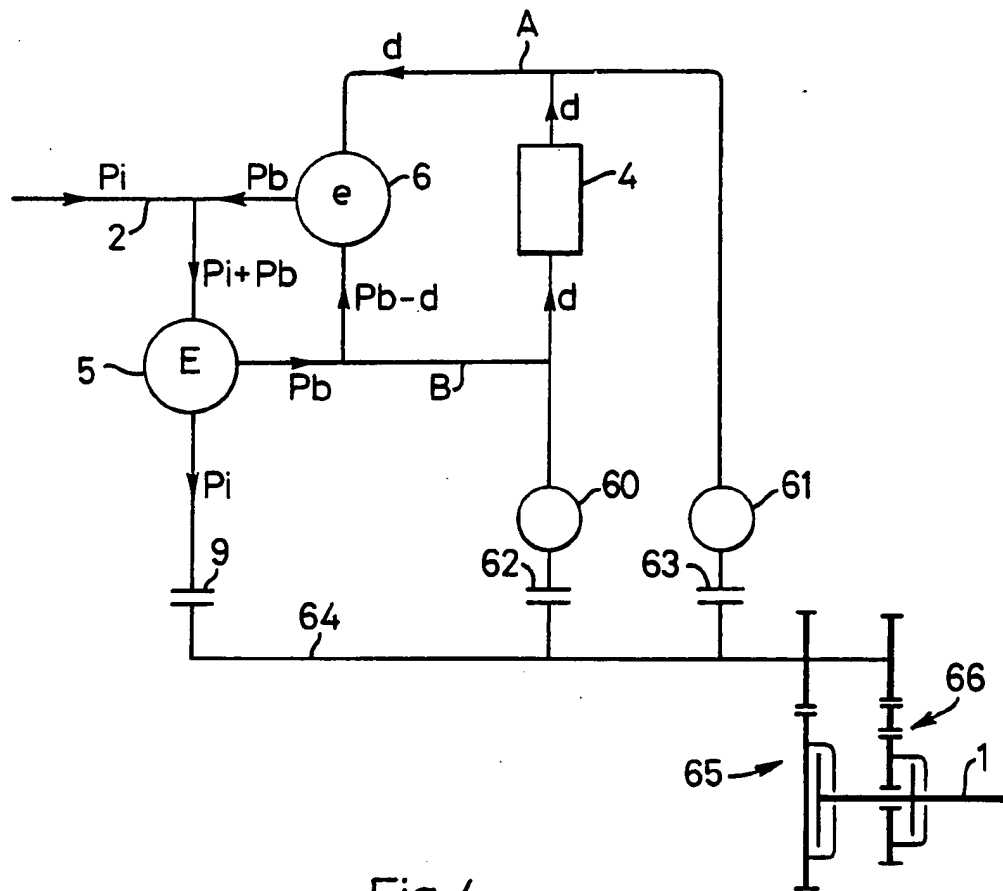


Fig. 4

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IMPROVEMENTS IN OR RELATING TO  
CONTINUOUSLY-VARIABLE-RATIO TRANSMISSIONS

This invention relates to continuously-variable-ratio transmissions ("CVT's"). The invention is broadly applicable to such CVT's in which the variator - that is to say, the ratio-varying component - is incapable of achieving zero ratio. That is to say, although the speed of rotation of the output member can be varied steplessly over a predetermined range, while the input member rotates at constant speed, the output speed range does not include zero. To enable the transmission to deliver zero output speed, it is customary to drive the CVT output from one component of an epicyclic gear unit, the other two components of which are connected, through gearing as necessary to match the epicyclic ratio, to the output and input of the variator. When such a variator and an epicyclic are so combined it becomes possible, if the variator input speed is held steady and the variator is then traversed from one end of its ratio range to the other, to cause the CVT output speed to change continuously, first falling from a maximum speed in one direction to zero and then continuing by rising to a maximum in the other direction. Throughout this process, and particularly at the moment (known in the art as "geared neutral") when the output speed is zero, the epicyclic will be recirculating power through the variator and other components of the CVT. Such an epicyclic is therefore known in the art as a "recirculating epicyclic".

It is also well-known in the art, and especially where the variator is of the toroidal-race rolling-traction type, to extend the ratio range of the CVT by introducing gearing and clutches whereby the variator is enabled to work in more than one "regime". That is to say, once the rollers of a variator of that type have swept from one end of their ratio angle range to the other, so progressing the CVT output speed from one value to another and perhaps with change of direction as just described,

by operation of clutches so as to engage different gearing it is then possible to sweep the rollers back over their range of movement in the opposite direction and in so doing to progress the CVT output speed still further. By correct choice of gear ratios it is possible to change thus from one regime to another without instantaneous change of CVT output speed. Such a regime change is known in the art as a synchronous change.

The present invention seeks to provide a CVT of the toroidal-race, rolling-traction type, capable of geared neutral and of operating in at least two regimes, with a specially convenient facility for incorporating extra regimes in both forward and reverse, and also with the facility to limit the power passing through the variator, particularly at or close to the geared neutral condition. This power limitation can offer the prospect of providing substantial advantages, including reduced variator size, particularly in vehicles such as excavator trucks which are often required to deliver high torque when moving at low or zero road speed.

The invention is defined by the claims and includes the CVTs as shown in the accompanying, simplified and schematic drawings. The invention will now be described, by way of example, with reference to these drawings in which:-

- Figure 1 is a system diagram;
- Figure 2 compares shaft speeds graphically;
- Figure 3 shows one embodiment of a CVT, and
- Figure 4 shows one alternative to the system diagram of Figure 1.

In Figure 1 a CVT having an output shaft 1 and input shaft 2 (for connection to a prime mover at 3) comprises a toroidal-race variator 4, a recirculating epicyclic E (reference 5) and an input epicyclic e (reference 6). References 7, 8, indicate the shafts connected to the first and second operating members of variator 4. These members cannot as usual be referred to simply as the "input" and "output" members because, as will be seen, they exchange these functions as the CVT moves between regimes.

By way of shafts A and B the shafts 7, 8 are connected respectively to two of the components (for instance the sun and the planet carrier) of input epicyclic e, the third component of which (e.g. the ring gear) is connectable to the prime mover 3.

5 The same shafts A and B are also connected, also by way of appropriate gearing, with two components (e.g. the sun and planet carrier again) of the recirculating epicyclic E and the third component (e.g. the ring) of unit E is connectable, in the regime including geared neutral, by way of low regime clutch 9 with the

10 output shaft 1. In the diagrammatic form of Figure 1, it will therefore be apparent that the speeds of rotation of shafts A and B, whose speeds of rotation are directly related to those of shafts 7 and 8, always move in antiphase as the rollers of variator 4 change orientation one way or the other, within their

15 range of angular movement. Thus as they move from one end of that range to the other, one of shafts A, B will accelerate and the other slow down. As the rollers then traverse back again, as they will do in a successive "regime", the speeds of shafts A, B will change in the opposite sense.

20 In low regime clutch 9 will be closed, power will recirculate through epicyclic E, and as variator 4 progresses from one end of its ratio range to the other the speed of output shaft 1 can be arranged to make the typical, continuous "low regime" progression from a finite value in one direction, falling to zero and then

25 climbing to a second finite value in the other direction. For all other regimes that may be required clutch 9 is disengaged, epicyclic E ceases to recirculate power and output 1 is driven by way of one of gearing/clutch combinations (10, 11; 12, 13; 14, 15; 16, 17; 18, 19; 20, 21 etc.,) from whichever of shafts A and

30 B starts the respective regime at its lowest speed and rises to its highest during that regime. Thus, following the end of low regime at which output 1 is rotating forwards, and assuming shaft A is then rotating at its slowest speed, clutch 9 could be disengaged and clutch 11 engaged to put the CVT into a "middle"

35 forward regime in which output 1 is driven by shaft A through

gearing 10 until the relative speeds of shafts A, B have reached the opposite extreme value, when clutch 11 can be disengaged and clutch 13 engaged to enter a further, "high" forward regime in which shaft 1 is driven from shaft B through a different set of fixed gearing 12. If however the CVT reaches the end of low regime at which output shaft 1 is rotating in reverse, and it is wished to provide further "middle" and "high" reverse gears and to progress the CVT through those gears, then because shaft B will then be rotating at its slowest speed a typical sequence of clutch operation would be to disengage 9/engage 17 so as to drive the output by shaft B through fixed gearing 16 in "middle reverse", and then to disengage 17/engage 15 to drive the output from shaft A through further fixed gearing 14 in "high reverse". Items 18-21 indicate clutch/gearing combinations by which yet further regimes, forward and reverse, can simply be added. The ratios of variator 4, epicyclic E, and gearing sets, 10, 12, 14 etc., must of course be chosen, in a manner well known in the art, so that the clutch engagements/disengagements between regimes are achieved synchronously, as already described, without instantaneous change of the transmitted ratio.

Figure 2 is a simplified graphical representation of the typical relationship between the speed of rotation of output shaft 1 (x-axis) and the speed of shafts A and B (y-axis). Points 25-28 indicate the regime change points low-middle forward, low-middle reverse, middle-high forward and middle-high reverse respectively. It should be specially noted that the x-axis scale, as shown in this simplified Figure, is non-linear. Were it linear, the lines would typically be steep close to the y-axis, and would progressively flatten as they moved away from it in either direction.

In the practical embodiment of the invention shown in Figure 3, parts directly comparable with those already introduced in Figure 1 carry the same references. Input shaft 2 drives the ring gear 35 of input epicyclic e, and the sun 36 drives shaft A (-7) which carries the input discs 37 of the toroidal-race



variator 4. Reference 38 indicates two of the variable-orientation rollers (typically six in all) of that variator, and 39 an arrow indicating the direction in which the rollers tilt during any one regime so as to change their "ratio angle" and thus the transmitted ratio. The planet carrier 40 of epicyclic e is connected by a gear train 34 to shaft B, which is also connected to the output discs 41 (=8) of variator 4 without change of direction by a chain 42. Shaft A also carries halves of clutches 44 and 45, and shaft B halves of clutches 46 and 47. The other half of clutch 47 is carried by the CVT output shaft 1. Two further clutches 48, 49 are provided.

To engage low regime, clutches 44, 46 are engaged and all the other clutches are open. By way of clutch 44, shaft A now drives the sun 50 of recirculative epicyclic E, and by way of clutch 46 and a reduction gearing train 51 shaft B drives the planet carrier 52. Power is recirculated within unit E and the output is delivered to shaft 1 by way of the ring gear 53 and a reduction gear train 54. When engaged together, clutches 44, 46 thus behave like clutch 9 of Figure 1.

To change from low to middle forward regime, clutch 46 is opened and 48 closed, and clutch 44 remains closed. This has the effect of "locking" unit E so that it no longer recirculates power but instead rotates as one, and drive is transmitted to output shaft 1 from shaft A by way of the sun 50, the locked unit E and the same reduction gear train 54. Clutch 48 may thus be compared to clutch 11 of Figure 1. To change from low to middle reverse regime, clutch 49 is closed and 44 opened, while clutch 46 remains closed. Drive is now transmitted to output shaft 1 from shaft B by way of clutch 46, reduction gearing 51, the planet carrier 52, clutch 49 and a reduction gear train 55 which also reverses motion relative to gear train 54. Clutch 49 may thus be compared with clutch 17 of Figure 1, and in this regime the sun 50 and ring 53 of epicyclic E transmit no power. For the change between middle and high forward regimes, clutches 44, 48 are opened and clutch 47 is closed. Drive is now transmitted

directly by the closed clutch 47 from shaft B to shaft 1. For the change between middle and high reverse regimes, clutches 46, 49 are opened and clutch 45 closed, and drive will then be transmitted directly from shaft A, by way of closed clutch 45 and gear train 55, to output shaft 1. Clutches 47, 45 thus equate with clutches 13, 15 in Figure 1.

Assuming 100% efficiency, in the operation of any CVT the input power  $P_i$ , which equals the product of the speed  $N_i$  and torque  $T_i$  in input shaft 2, must equal the output power  $P_o$ , which equals the product of output speed  $N_o$  and torque  $T_o$  in output shaft 1. In embodiments of the invention as described with reference to Figures 1 and 3 it can easily be arranged that the power transmitted through the variator 4 is considerably less than  $P_i$  in all regimes except low. In low regime, however, it may sometimes prove difficult to select gear ratios and other relative parameters so as to prevent the maximum variator power from rising inconveniently high. The maximum power which a toroidal-race variator must transmit is a key factor in determining the size and cost of such a variator, so there are clear advantages in minimising that maximum power. Figure 4 shows an alternative to the system diagram of Figure 1, in which the relationship between input shaft 2, input epicyclic e, variator 4 and shafts A and B is as before, but recirculating epicyclic E is displaced so that it now connects with shaft B, low regime clutch 9 and input shaft 2, instead of with clutch 9 and shafts A and B as before. Arrows indicate the recirculation of input power  $P_i$  and the power  $P_b$  in shaft B within low regime, the symbol d indicating a power quantity which is greater than zero but less than  $P_b$ . In the embodiment of Figure 4 further gearing 60, 61 and clutches 62, 63 are used to provide middle and higher regimes. The clutches 9, 62 and 63 all engage the drive with a layshaft 64 which will be driven in the same rotary sense in all regimes. If many regimes are required, using the layout of Figure 1, the numbers of gears and clutches may be large. In a symmetrical "forward-and-reverse" system the number of gears

and clutches can be halved, as in Figure 4, by providing downstream forward and reverse gear assemblies 65 and 66. Having done so, low regime need only cater for output speeds from around zero (that is to say, geared neutral) to the low/middle regime  
5 synchronous change speed in one direction. This asymmetry enables the recirculating epicyclic E to be connected to the prime mover (via 2) and to only one side of the variator 4 (via shaft B), thus reducing the power transmitted through the variator. Another potentially advantageous aspect of the  
10 embodiment of Figure 4 that should be noted is that the higher regime trains are used in both forward and reverse drive.

From the foregoing it will be seen that the invention may include a CVT in which the variator is not only combined with a recirculating epicyclic, but at least one of the two sides of the  
15 variator is also connected to a component of a second, input epicyclic, another component of which is connectable to the prime mover. Clutches and gearing are then also provided whereby power is recirculated through the recirculating epicyclic in the regime which includes geared neutral, but whereby in successive further  
20 regimes the recirculating epicyclic is by-passed and the drive reaches the CVT output, by way of appropriate clutches and gearing, from whichever side of the variator will rise in speed as that regime proceeds.

CLAIMS

1. A continuously-variable-ratio transmission ("CVT") capable of geared neutral and of operating in at least two regimes, and including a ratio-varying component ("variator") (4), a power-recirculating epicyclic (E), an input epicyclic (e) the input (35) of which is connectable (via 2) to a prime mover (3), and a final drive shaft (1) connectable with the variator by way of one of two alternative driven shafts (A, B) characterised in that the power-recirculating epicyclic (E) is associated with appropriate clutches (44, 46) whereby power is recirculated through that epicyclic in one of the regimes which includes geared neutral, but whereby in the remaining one or more regimes no power is recirculated within it and the drive reaches the CVT output (1) by way of appropriate clutches (44, 46; 48, 47; 49, 45) and of whichever of the two driven shafts (A, B) will rise in speed as that regime proceeds, and in that the two shafts (A, B) are respectively connected both to opposite sides of the variator (4) and to different output members (36, 40) of the input epicyclic (e).
2. A CVT according to Claim 1, characterised in that there are at least three regimes, in at least one of which the final drive shaft (1) rotates in the forward direction throughout the regime, and in at least one other of which it rotates in the reverse direction throughout the regime.
3. A CVT according to either of the preceding claims in which the variator is of the toroidal-race rolling-traction type.
4. A CVT according to Claim 1, substantially as described with reference to the accompanying drawings.

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**Patents Act 1977**  
**Examiner's report to the Comptroller under Section 17**  
**(the Search report)**

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**Relevant Technical Fields**

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(ii) Int Cl (Ed.5) F16H 37/08

Search Examiner  
JIM CALVERT

Date of completion of Search  
10 MARCH 1994

**Databases (see below)**

(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE DATABASES : CLAIMS

Documents considered relevant following a search in respect of Claims :-  
1-4

**Categories of documents**

- |  |   |
|--|---|
| <p><b>X:</b> Document indicating lack of novelty or of inventive step.</p> <p><b>Y:</b> Document indicating lack of inventive step if combined with one or more other documents of the same category.</p> <p><b>A:</b> Document indicating technological background and/or state of the art.</p> | <p><b>P:</b> Document published on or after the declared priority date but before the filing date of the present application.</p> <p><b>E:</b> Patent document published on or after, but with priority date earlier than, the filing date of the present application.</p> <p><b>&amp;:</b> Member of the same patent family; corresponding document.</p> |
|--|---|

Category	Identity of document and relevant passages	Relevant to claim(s)
A	GB 2267323 A (TOROTRAK) - see Claim 1	1
A	WO 92/21896 A1 (ARAGONESA) - see Figure 1	1
A	US 4599916 (AISIN SEIKI) - see Figure 9	1

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).